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# (54) OPTO-ELECTRONIC SCALE READING APPARATUS.

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US-A-3 344 700

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**Description**

This invention relates to opto-electronic scale reading apparatus, of the kind comprising a scale defined by spaced lines, a read head, the read head and the scale being relatively movable in the direction of spacing of the lines. The read head is adapted to project light onto the scale, and determine, from the light pattern passed on by the scale, the magnitude and direction of the relative movement. Such apparatus is known generally from GB—A—1,504,691, EP—A—163362 (see also EP—A—132978) and DE—A—2720195.

EP—A—163362 discloses a light beam, incident on a scale via an index grating, which is diffracted into three orders (+1, 0, −1) by the scale, and which upon passing through an analyser grating, splits into three distinct phase-shifted beams. Relative motion of the scale and the read head causes a modulation of the light intensity passing through the analyser grating in respect of each of these beams. The intensity modulation of each of the beams is detected by a corresponding detector. Three beams are required to determine both the magnitude and direction of relative movement of the scale and the read head.

A problem with such an apparatus is that using the scale to produce the plurality (in this case three) of beams limits the direction of splitting of the beams to the direction of spacing of the lines on the scale. Furthermore, the scale and analyser grating must be of diffraction quality in order to produce the beams, thus making the apparatus expensive to produce.

To overcome this problem the present invention provides an opto-electronic scale reading apparatus comprising a scale (11; 211) defined by spaced lines (17) and a read head (10), the scale (11; 211) and the read head (10) being relatively movable in the direction of spacing of the lines, the read head (10) comprising:

a plurality of light emitters (15) for projecting a plurality of light beams onto the scale (11; 211), the light beams being incident upon a common region of the scale (11; 211);

each beam having a first grating (35) provided in its path upbeam of the scale (11; 211) and an analyser grating (45) in its path downbeam of the scale (11; 211);

the first grating (35) and the scale (11; 211) cooperating to produce at the analyser grating (45) in respect of each beam a light intensity modulation (MA, MB, MC) the said intensity modulations (MA, MB, MC) having a phase shifted relationship; and

a plurality of detectors (25A, 25B, 25C), each detector being positioned downbeam of the analyser grating (45) to detect only one of the said beams, wherein each detector (25A, 25B, 25C) produces an output signal (A, B, C) corresponding to the said light modulation (MA, MB, MC) of the respective beam.

Embodiments of apparatus according to this invention will now be described with reference to the accompanying drawings wherein:—

Figure 1 is a sectional view a first embodiment of the apparatus.

Figure 2 is a section on the line II—II in Figure 1 and an associated circuit diagram.

Figure 3 is a diagram for explaining the vector geometry associated with the above circuit diagram.

Figure 4 is an expanded diagram representation of Figure 3 and an associated phase diagram.

Figure 5 is a view similar to Figure 4 but shows a modification.

Figure 6 is a sectional view of a second embodiment of the apparatus.

Figure 7 is a sectional view of a third embodiment of the apparatus.

Figure 8 is a view on the line VIII—VIII in Figure 7.

Figure 9 is a view of a fourth embodiment.

Figure 10 is a view on the line X—X in Figure 9.

Referring to Figures 1 to 4, the apparatus is described with reference to the coordinates X, Y, Z of the orthogonal coordinate system. A read head 10 is movable relative to a scale 11 in the X-direction. The scale 11 comprises a body 16 having scale marks defined by the lines 17 extending in the Y-direction and spaced in the X-direction. The lines lie at an XY surface 18 of the scale 11. The read head 10 comprises a collimating system in the form of an axisymmetric collimating lens 12 having an optical axis 12Z perpendicular to an XY plane. The lens 12 is arranged for its collimating side to face the scale 11. The other or focussing side of the lens 12 faces an array of three light emitters 15 and three light receivers 25 all arranged about the axis 12Z in a common XY plane perpendicular thereto. In the present example the emitters 15 and receivers 25 are opto-electronic diodes. Each emitter 15 is substantially a point source of divergent light and is spaced from the axis 12Z by a radial offset 15R. As a result the lens 12 produces an incident beam 13 of collimated light projected along an axis 13R toward the axis 12Z. It will be clear that, by virtue of the offsets 15R, the axes 13R associated with the respective beams 13 intersect at a common point 30P and the beams 13 intersect at a common region 30 lying in an XY plane. The relative position of the read head 10 and the scale 11 in the Z-direction is such that the region 30 lies at the surface 18. The incident beams 13 are reflected by the scale 11 to produce reflected beams 14 having axes 14R. The lens 12 focusses the beams 14 on to the respective receivers 25 which are spaced from the axis 12Z by radial offsets 25R corresponding to the offsets 15R.

It may be said that the emitters 15 define a group of emitting devices having the lens 12 in common, and that the receivers 25 define a group of receiving devices having the lens 12 in common. In the present example the lens 12 is common to both said groups. As shown in Figures 2 and 4 there are three pairs of associated emitters and receivers denoted 15A, 25A; 15B, 25B; 15C, 25C, wherein the two elements of each pair, e.g. 15A, 25A, are situated on diametrically

opposite sides of the axis 12Z as required by the lens 12. In the present example the emitters and receivers are arranged so that the emitters are spaced along a line 15X extending in the X-direction at one side of the axis 12Z and the receivers are correspondingly spaced along a line 25X in the X-direction at the other side of the axis 12Z. Each pair of emitters and receivers 15, 25 is associated with a pair of gratings 35, 45 situated respectively in the projected and the reflected beams 13, 14 between the lens 12 and the scale 11. Thus there are three grating pairs 34A, 45A; 35B, 45B; 35C, 45C, associated respectively with the emitter and receiver pairs 15A, 25A; 15B, 25B; 15C, 25C. The gratings 35, 45 lie in a common XY-plane and are defined by lines 37, 47 which are parallel to the lines 17 of the scale.

Each pair of emitters and receivers 15, 25 and the associated pair of gratings 35, 45 are referred to as a phase unit 46. Each phase unit 46 is designed so that, during said relative movement of the scale and the read head, the relevant receivers 25A, 25B, 25C see respective sinusoidal light modulations M, respectively denoted MA, MB, MC, produced by the optical interaction of the scale 11 with the gratings 35, 45 of the respective unit 46. The modulations M have a period which is constant with respect to the pitch of the scale lines 17. However, each modulation M may be regarded as a moire fringe manifest as the alternation of light and dark distributed over the aperture of the receiver. So long as the lines 17, 37, 47 are absolutely parallel the period of the moire fringes is said to be equal to infinity. Otherwise that period is finite.

The gratings of each grating pair 35, 45 have a phase separation which is offset from the corresponding phase separation of each of the other pairs nominally by 120°. In other words the phase interval between any adjacent pair MA, MB or MB, MC or MC, MA is nominally 120° (Figure 4).

The receivers 25 have electrical outputs A, B, C which have the same phase separation as the modulations M.

The modulations M may be produced by optical interaction of the scale and the gratings as described in our International Application No. PCT/GB85/00600 or by any other such interaction.

The signals A, B, C are connected to a circuit 50 having differential amplifiers 51, 52 for producing signal values B−A and B−C, and further differential amplifiers connected to produce signal values A−C and 2B−(A+C) which define respectively the sine and cosine terms of any one of the signals A, B, C. The operation of the circuit 50 may be described as three-phase derivation of the sine and cosine terms of the light modulations independently of light level. Four-phase derivation may be used but three-phase are more appropriate in the context of this invention because it requires only three emitter and receiver pairs which are more readily accommodated in the aperture of the lens, compared to four such pairs normally required for four phases.

Referring to Figure 3, the three outputs A, B, C are shown as vectors A1, B1, C1. The vectors A1 and C1 respectively lead and trail the vector B1. The vector sum −(A1+C1) has the same phase angle as the vector B1 and occurs between the vectors A1, C1, and the vector sum 2B−(A+C) is shown superimposed on the vector B1. The vector sum A1−C1 occurs between the vectors A1, B1 at an angle of 90 degs. with the vector B1, thus signifying the sine and cosine relationship between the terms 2B−(A+C) and A−C. Said 90 deg. relationship is preserved so long as the vectors A1, C1 respectively lead and trail the vector B1 by like amounts, and this relationship is not disturbed (within reasonable limits) by the absolute values of the phase angles between the vectors A1, C1 and C1, B1. Also the circuit operates to compensate for phase errors so long as these errors are uniform, i.e. so long as the vectors A1 and C1 lead and trail the vector B1 by like amounts as mentioned herein above.

Reference is now made to how the apparatus copes with errors which may arise from manufacturing tolerances. It will be clear that since the axes 13R intersect at the common point 30P so that the region 30 is common to the three phase units 46, the apparatus according to this invention is substantially immune to errors due to variations in reflectance or phase differences between different portions of the scale. Also the scale 11 can be narrow in the Y-direction compared to a scale where three or perhaps four phase units require separate regions of the scale spaced in the Y-direction.

Regarding a yaw misalignment and consequent moire and phase errors, a yaw error would exist if the angular position of the read head 10 relative to the scale 11 about a Z-axis, e.g. the axis 12Z, is such that the lines 17, 37, 47 are not parallel. This would result in a moire error, i.e. in the period of the moire fringes becoming finite, and would result in a corresponding change in the phase separation of the modulations M. However, since the axes 13R intersect at the common point 30P the arrangement is optically equivalent to each unit 46 lying, notionally, on the axis 12Z. Hence the phase separation between the modulations M remain unchanged.

A tolerance in the stand-off of the read head, i.e. in the spacing of the read head 10 and the scale 11 in the Z-direction, may result in the common point 30P not lying exactly at the plane 18. As a result, since the emitters and receivers are aligned in the X-direction, there is produced a phase error by triangulation. This condition can be eliminated or reduced by arranging the emitters and receivers along respective lines in the Y-direction instead of in the X-direction as shown in Figure 5. This results in the axes 13R not intersecting the plane 18 at the same point 30P but the intersections occur at three points one of which is on the axis 12Z while the other two are spaced to opposite sides thereof in the Y-direction so that there can be no phase error. However, when the emitters and receivers are so aligned, a yaw misalignment will produce moire fringes of finite period with a

consequent occurrence of equal phase errors between adjacent pairs of the modulations M. This condition can be tolerated because equal phase errors can be eliminated by the circuit 50 as mentioned above.

Referring to Figure 6, there is shown apparatus similar to that shown in Figures 1—4 but applied to a transmissive scale 211. The apparatus comprises three phase units 246 wherein three light emitters 15 illuminate a first collimating lens 212 which produces collimated beams 213 converging to a common region 30 from which the beams emerge as emergent beams 214 which are focussed by a focussing lens 212F on to respective light receivers 225. Gratings 235, 245 in the beams 213, 214 produce light modulations substantially as described with reference to Figures 1 to 4. The lens 212 is common to the group of emitters 15. The lens 212F is common to the group of receivers 25. Either group could have individual lenses for its emitters or receivers as the case may be.

Referring to Figures 7 and 8, the apparatus comprises three phase units 346 wherein three light emitters 315 illuminate respective collimating lenses 312 defining individual collimating systems for the respective units.

The lenses 312 produce collimated beams 313 along respective convergent axes 313R converging on to a common region 30 on a scale 11 which reflects the light in the form of beams 314 and through focussing lenses 312F on to respective receivers 325. Gratings 335, 345 beams 313, 314, produce light modulations substantially as described with reference to Figures 1—4.

Referring to Figures 9 and 10, apparatus comprises three phase units 446 having emitters 15 and receivers 25 arranged substantially on a common line 15/25X extending in the X-direction or, as shown in broken lines, substantially on a common line 15/25Y extending in the Y-direction. It will be seen that the emitter-receiver pair 15, 25 situated nearest the axis 12Z may be situated directly adjacent one another as shown.

It will be understood that the emitters may each be constituted by one end of a light transmitting fibre whose other end is connected to the appropriate receiving diode. Regarding the emitter/receiver pair situated nearest the axis 12Z, this pair may comprise a concentric emitter/receiver device or may be constituted by the end of a single light-transmitting fibre concentric with the axis 12Z and adapted to transmit both the incident and the reflected light.

**Claims**

1. Opto-electronic scale reading apparatus comprising a scale (11; 211) defined by spaced lines (17) and a read head (10), the scale (11; 211) and the read head (10) being relatively movable in the direction of spacing of the lines, the read head (10) comprising:

a plurality of light emitters (15) for projecting a plurality of light beams onto the scale (11; 211), the light beams being incident upon a common region of the scale (11; 211);

each beam having a first grating (35) provided in its path upbeam of the scale (11; 211) and an analyser grating (45) in its path downbeam of the scale (11; 211);

the first grating (35) and the scale (11; 211) cooperating to produce at the analyser grating (45) in respect of each beam a light intensity modulation (MA, MB, MC) the said intensity modulations (MA, MB, MC) having a phase shifted relationship; and

a plurality of detectors (25A, 25B, 25C), each detector being positioned downbeam of the analyser grating (45) to detect only one of the said beams, wherein each detector (25A, 25B, 25C) produces an output signal (A, B, C) corresponding to the said light modulation (MA, MB, MC) of the respective beam.

2. An apparatus according to claim 1 wherein the apparatus has manufacturing tolerances producing errors in the light modulations.

3. An apparatus according to claim 2, wherein different portions of the scale (11) have varying reflectance.

4. An apparatus according to claim 2 or claim 3 wherein different portions of the scale (11) have phase differences.

5. An apparatus according to any one of claims 2 to 4 wherein the scale (11) and the read head (10) are misaligned with respect to each other.

6. An apparatus according to any one of the preceding claims comprising means (50) for producing from the said output signals (A; B; C) a pair of sinusoidally varying signals (A−C; 2B−[A+C]) having a quadrature relationship.

7. An apparatus according to any one of the preceding claims wherein the analyser grating (45) comprises a plurality of adjacent identical individual gratings (45A, 45B, 45C) being mutually offset by a fraction of the individual grating pitch in the direction of propogation of the light, thereby to produce the said optical modulations in the phase-shifted relationship.

8. An apparatus according to any one of the preceding claims wherein the scale (11), the index grating (35) and the analyser grating (45) all lie in substantially parallel planes.

9. An apparatus according to any one of the preceding claims wherein the light emitters (15) are opto-electronic diodes.

10. An apparatus according to any one of the preceding claims wherein the number of light beams is three, and the phase shifted relationship between any given pair of the three beams is an integer multiple of 120°.

**Patentansprüche**

1. Opto-elektronische Skalen-Ablesevorrichtung mit einer durch mit gegenseitigem Abstand angebrachte Linien (17) definierten Skala (11; 211) und einem Lesekopf (10), wobei die Skala (11; 211) und der Lesekopf (10) in Richtung der

Abstände der Linien relativ zueinander bewegbar sind, und der Lesekopf (10) umfaßt:

eine Vielzahl von Lichtemittern (15) zum Aussenden einer Vielzahl von Lichtstrahlen auf die Skala (11; 211), die auf einem gemeinsamen Bereich der Skala (11; 211) auftreffen;

wobei in dem Weg jedes Strahls in Strahlrichtung vor der Skala (11; 211) ein erstes Gitter (35) und in seinem Weg in Strahlrichtung nach der Skala (11; 211) ein Analysatorgitter (45) vorgesehen ist;

das erste Gitter (35) und die Skala (11; 211) zusammenwirkend an dem Analysatorgitter (45) mit Bezug auf jeden Strahl eine Lichtintensitäts-Modulation (MA, MB, MC) erzeugen und die Intensitätsmodulationen (MA, MB, MC) eine Phasenschiebe-Beziehung aufweisen; und

eine Vielzahl von Detektoren (25A, 25B, 25C), von denen jeder Detektor in Strahlrichtung nach dem Analysatorgitter zur Erfassung nur eines Strahls angeordnet ist, wobei jeder Detektor (25A, 25B, 25C) ein der Lichtmodulation (MA, MB, MC) des jeweiligen Strahls entsprechendes Ausgangssignal (A, B, C) erzeugt.

2. Vorrichtung nach Anspruch 1, bei der die Vorrichtung Fehler bei den Lichtmodulationen erzeugende Herstelltoleranzen besitzt.

3. Vorrichtung nach Anspruch 2, bei der unterschiedliche Abschnitte der Skala (11) abweichendes Reflexionsvermögen besitzen.

4. Vorrichtung nach Anspruch 2 oder 3, bei der unterschiedliche Abschnitte der Skala (11) Phasendifferenzen besitzen.

5. Vorrichtung nach einem der Ansprüche 2 bis 4, bei der die Skala (11) und der Lesekopf (10) zueinander fehl-ausgerichtet sind.

6. Vorrichtung nach einem der vorangehenden Ansprüche mit Mitteln (50) zur Erzeugung von zwei sich sinusartig ändernden Signalen (A−C; 2B−[A+C]) mit 90°-Beziehung aus den Ausgangssignalen (A; B; C).

7. Vorrichtung nach einem der vorangehenden Ansprüche, bei der das Analysatorgitter (45) eine Vielzahl von einander benachbarten identischen Einzelgittern (45A, 45B, 45C) umfaßt, die gegenseitig um einen Bruchteil der Einzelgitter-Schrittweite in der Fortpflanzungsrichtung des Lichts versetzt sind, um dadurch die optischen Modulationen der Phasenschiebe-Beziehung zu erzeugen.

8. Vorrichtung nach einem der vorangehenden Ansprüche, bei der die Skala (11), das Indexgitter (35) und das Analysatorgitter (45) in im wesentlichen parallelen Ebenen liegen.

9. Vorrichtung nach einem der vorangehenden Ansprüche, bei der die Lichtemitter (15) optoelektronische Dioden sind.

10. Vorrichtung nach einem der vorangehenden Ansprüche, bei der die Anzahl der Lichtstrahlen drei ist und die Phasenschiebe-Beziehung zwischen je zweien der drei Strahlen ein ganzzahliges Vielfaches von 120° ist.

**Revendications**

1. Dispositif opto-électronique de lecture de graduation, comprenant une graduation (11; 211) définie par des lignes espacées (17), et une tête de lecture (10), la graduation (11; 211) et la tête de lecture (10) étant mobiles l'une part rapport à l'autre dans la direction d'espacement des lignes, la tête de lecture (10) comprenant:

une pluralité d'émetteurs de lumière (15) pour projeter une pluralité de faisceaux lumineux sur la graduation (11; 211), les faisceaux lumineux étant incidents sur une région commune de la graduation (11; 211);

chaque faisceau possédant un premier réseau (35) prévu dans sa trajectoire en amont de la graduation (11; 211), et un réseau analyseur (45) dans sa trajectoire en aval de la graduation (11; 211);

le premier réseau (35) et la graduation (11; 211) coopérant pour produire une le réseau analyseur (45), pour chaque faisceau, une modulation d'intensité lumineuse (MA, MB, MC), les modulations d'intensité (MA, MB, MC) ayant une relation de décalage de phase; et

une pluralité de détecteurs (25A, 25B, 25C), chaque détecteur étant positionné en aval du réseau analyseur pour détecter un seul des faisceaux, dans lequel chaque détecteur (25A, 25B, 25C) produit un signal de sortie (A, B, C) correspondant à la modulation de lumière (MA, MB, MC) du faisceau respectif.

2. Dispositif selon la revendication 1, dans lequel le dispositif possède des tolérances de fabrication produisant des erreurs dans les modulations de lumière.

3. Dispositif selon la revendication 2, dans lequel les parties différentes de la graduation (11) ont une réflectance variable.

4. Dispositif selon la revendication 2 ou 3, dans lequel des parties différentes de la graduation (11) ont des différences de phase.

5. Dispositif selon l'une quelconque des revendications 2 à 4, dans lequel la graduation (11) et la tête de lecture (10) sont en désaxage l'une par rapport à l'autre.

6. Dispositif selon l'une quelconque des revendications précédentes, comprenant des moyens (50) pour produire, à partir des signaux de sortie (A; B; C), une paire de signaux à variation sinusoïdale (A−C; 2B−(A+C)) ayant une relation de quadrature.

7. Dispositif selon l'une quelconque des revendications précédentes, dans lequel le réseau analyseur (45) comprend une pluralité de réseaux individuels identiques adjacents (45A, 45B, 45C) qui sont mutuellement décalés d'une fraction du pas de réseau individuel dans la direction de propagation de la lumière, afin de produire les modulations optiques précitées dans la relation de décalage de phase.

8. Dispositif selon l'une quelconque des revendications précédentes, dans lequel la graduation (11), le réseau d'indexation (35) et le réseau analyseur (45) se situent tous dans des plans

sensiblement parallèles.

9. Dispositif selon l'une quelconque des revendications précédentes, dans lequel les émetteurs de lumière (15) sont des diodes opto-électroniques.

10. Dispositif selon l'une quelconque des revendications précédentes, dans lequel le nombre de faisceaux lumineux est de trois, et la relation de décalage de phase entre toute paire donnée des trois faisceaux est un multiple entier de 120°.

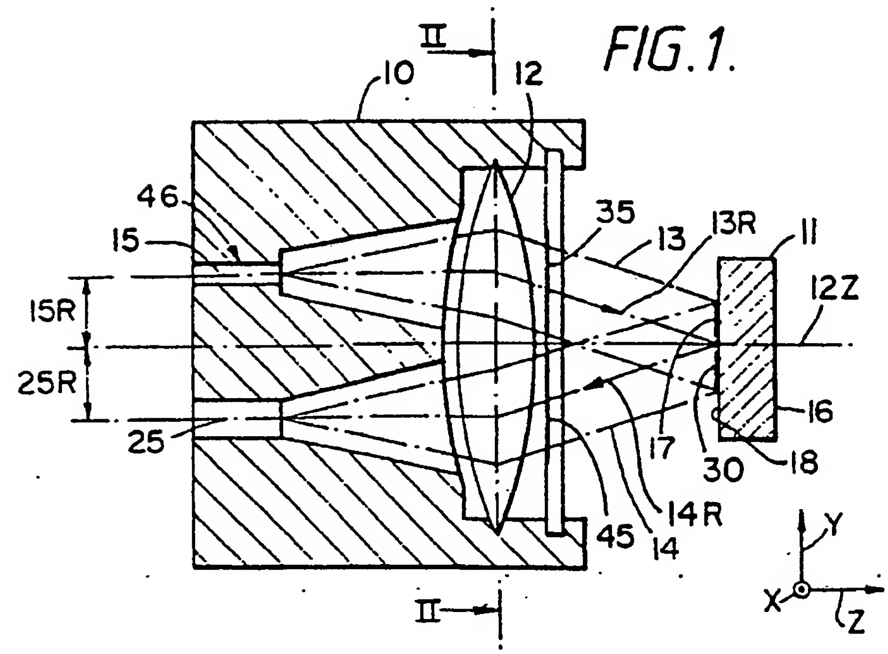
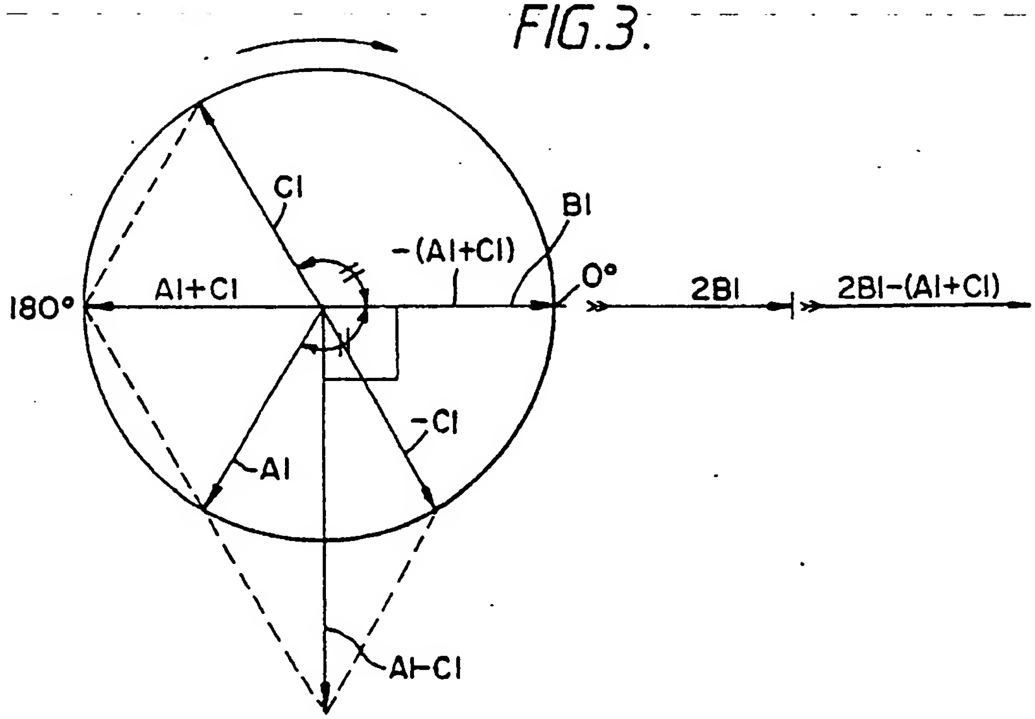

II
10
12
46
15
35
13
13R
11
12Z
15R
25R
25
17
30
16
18
45
14
14R
II
Y
X
Z

FIG.1.

FIG.3.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BI
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0°
2BI
2BI-(AI+CI)
180°
AI+CI
-CI
AI
AI-CI

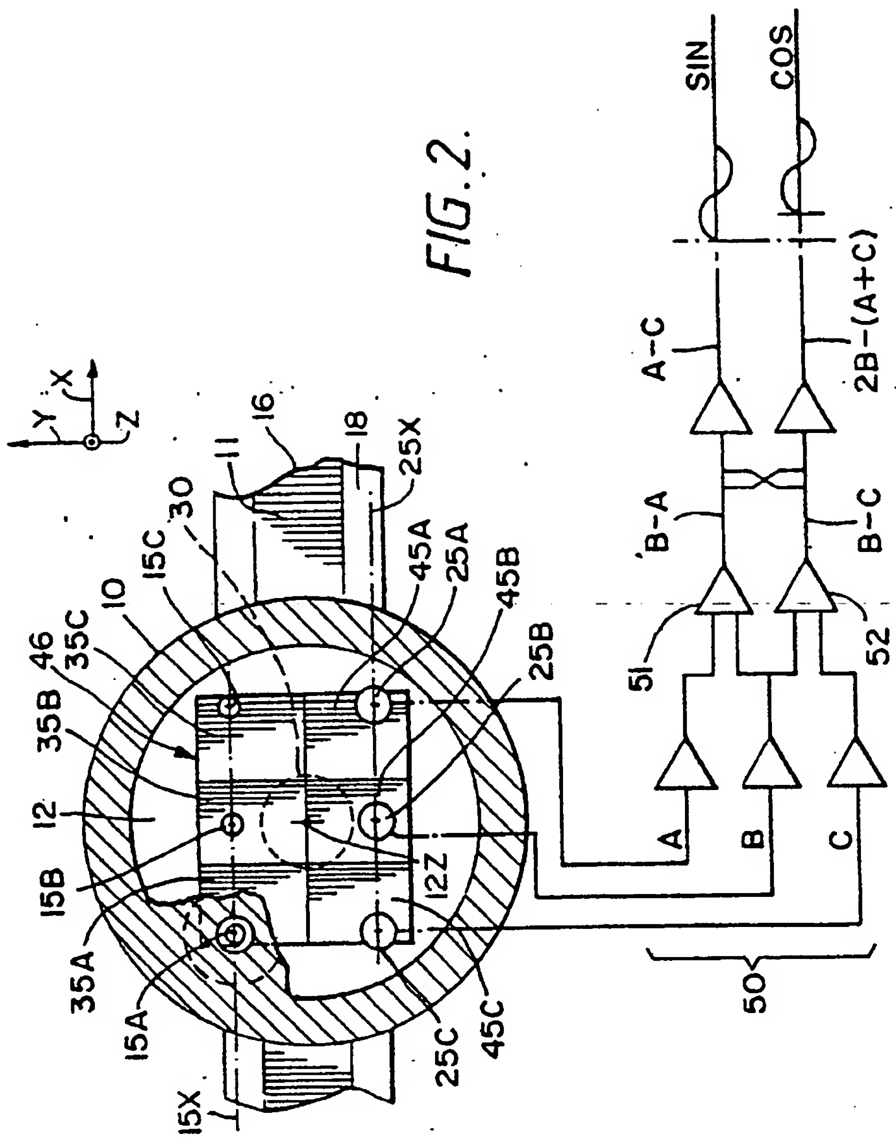

X
Y
Z
16
11
18
25X
30
15C
10
45A
25A
45B
35C
46
25B
35B
12
15B
12Z
35A
15A
25C
45C
15X
A
B
C
50
51
52
B-A
B-C
A-C
2B-(A+C)
SIN
COS

FIG. 2.

FIG. 4.

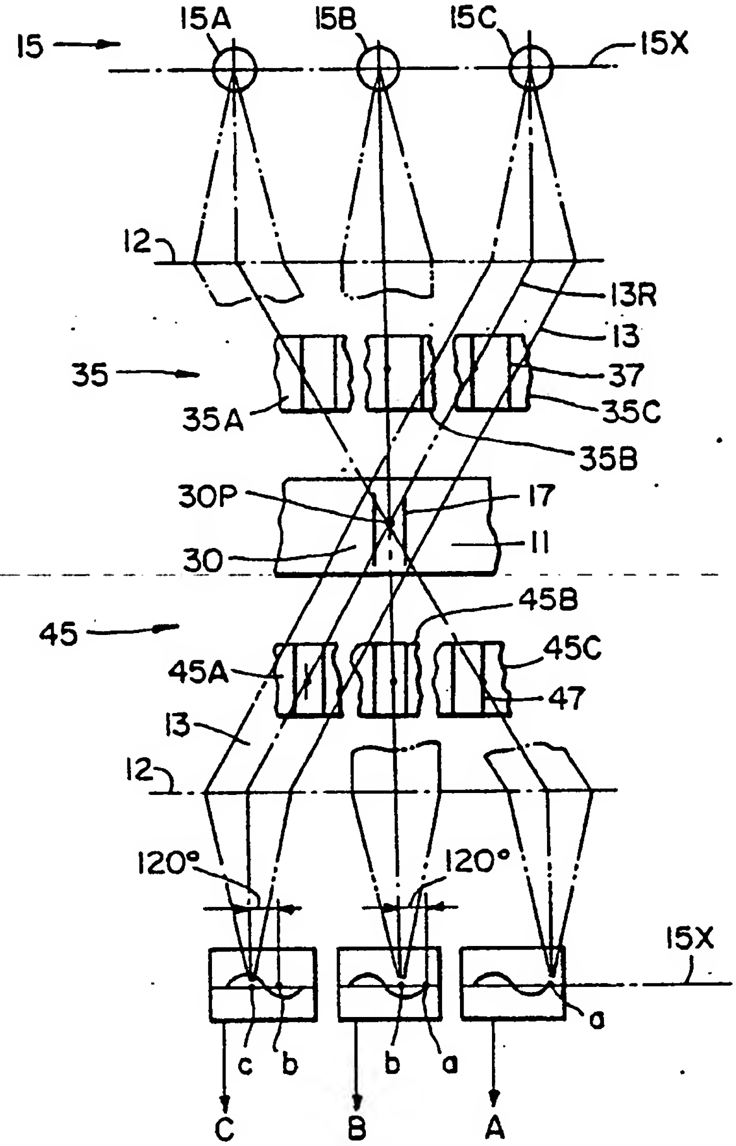
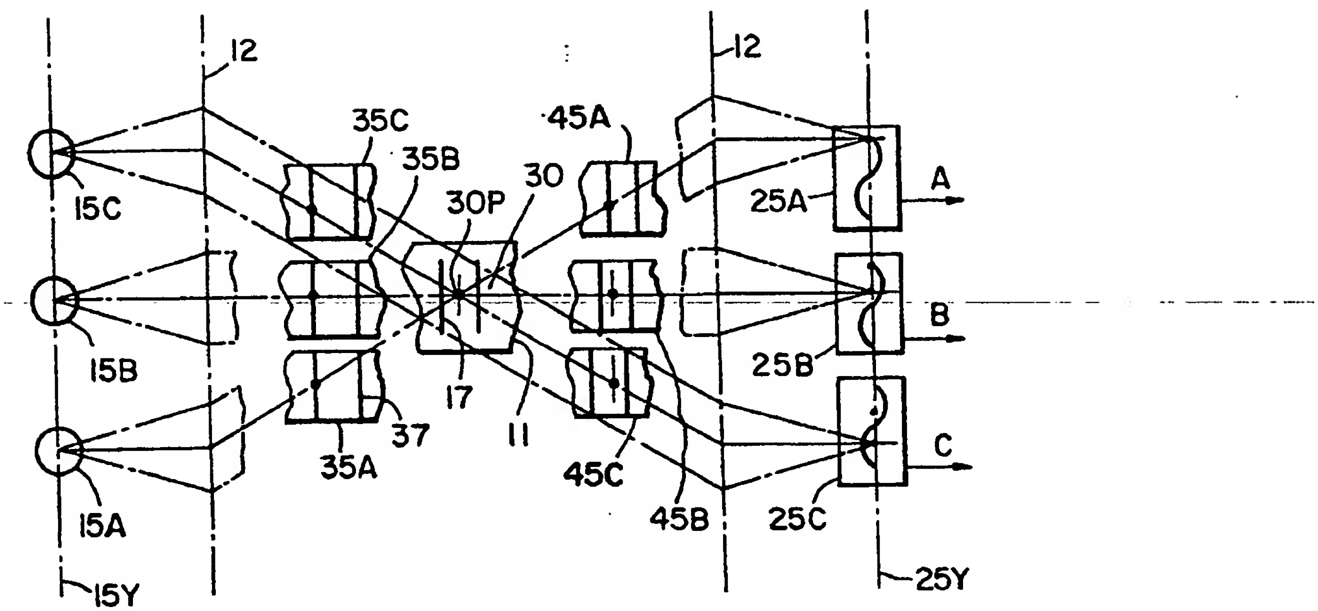

15
15A
15B
15C
15X
12
13R
13
35
37
35A
35C
35B
30P
17
30
11
45B
45
45C
45A
47
13
12
120°
120°
15X
c
b
b
a
a
C
B
A

FIG.5.


12
12
35C
45A
35B
30
30P
15C
25A
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15B
25B
B
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45B
25C
15Y
25Y

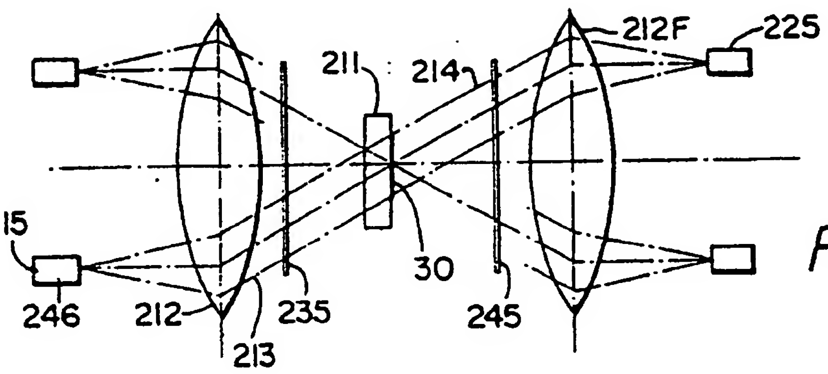


FIG.6.

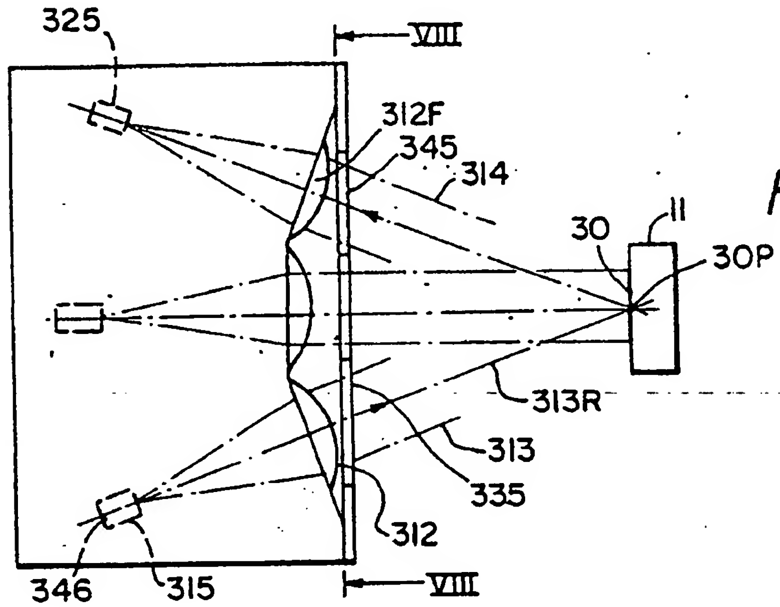


FIG.7.

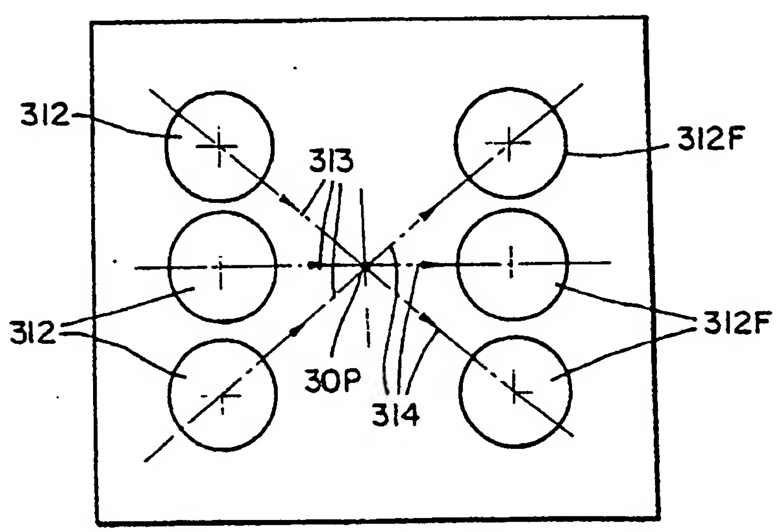


FIG.8.

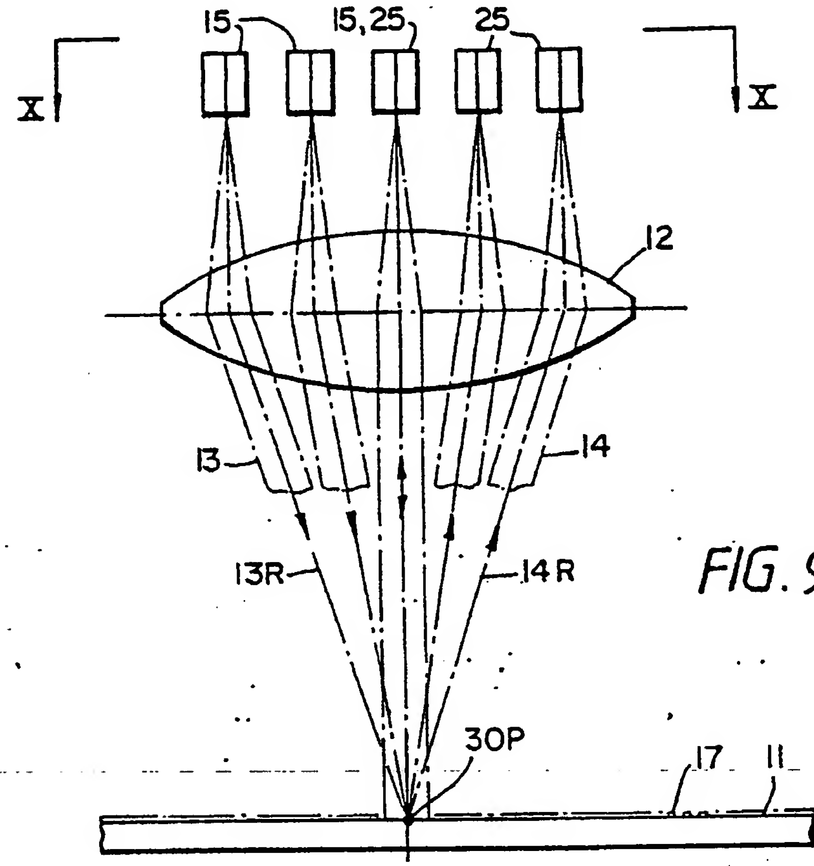
15
15,25
25
X
X
12
13
14
13R
14R
30P
17
11

FIG. 9.

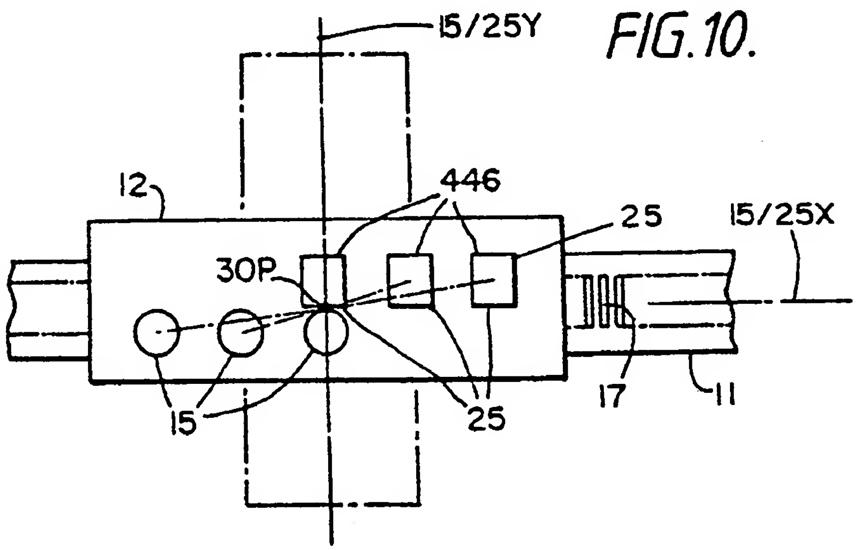
15/25Y
12
446
25
15/25X
30P
15
25
17
11

FIG.10.